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OF

ELECTRICAL ENGINEERS.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 15th, 1899.

The 133d meeting of the INSTITUTE was held this date at 12 West 31st street, and was called to order by President Kennelly at 8:10 P. M. The President requested the Secretary to make the customary announcements:

THE SECRETARY:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

Name.	Address.	Endorsed by
ADAMS, FRANK PIERCE	Electrician, Stockton Gas & Electric Co., residence, 171 N. El Dorado St., Stockton, Cal.	J. A. Lighthipe. C. E. Sedgwick. Geo. P. Low.
ADAMS, JULIUS LE ROY	Chief Engineer, Hartford, Manchester & Rockville Tramway Co., Manchester, Conn.	Oberlin Smith. M. J. Wightman. Ralph W. Pope.
BROWD, PAUL K.	Chief Engineer, The Russian Electric Company, "Union" St. Petersburg, Russia	L. B. Stillwell. Edw. L. Nichols. H. J. Ryan.
CURRIE, N. M.	Superintendent, The Municipal Electric Light Plant, Conneaut, Ohio.	A. L. Hadley. E. A. Barnes. F. S. Hunting.
CODMAN, JOHN STURGES	Consulting Engineer, Associated with R. S. Hale, 31 Milk St., residence, 57 Marlborough St., Boston, Mass.	Chas. R. Cross. H. V. Hayes. W. L. Puffer.
DUNN, CLIFFORD E.	Patent Attorney, 239 Broadway, New York City, residence, 12-a Monroe St., Brooklyn, N. Y.	Chas. A. Terry. Henry Schreiter. Ralph W. Pope.
HUTTON, CHAS. WILLIAM	Chief Electrician, Sacramento Electric Gas and Railway Co., Sacramento, Cal.	J. A. Lighthipe. C. E. Sedgwick. F. A. C. Perrine.
SCHWEITZER, EDMUND OSCAR	Electrical Inspector, Chicago Edison Co., 139 Adams St., residence 1906 Oakdale Avenue, Chicago, Ill.	W. E. Goldsborough C. P. Matthews. J. J. Flather.
TRUESDELL, ARTHUR E.	Assistant to General Superintendent, Peoples Light and Power Co., 443 4th Ave. Newark N. J.	Chas. R. Cross. Paul Spencer. Peter Wright.

WATERMAN, MARCUS B.	Electrical Engineer, Brewster Engineering Co., New York City, residence, 177 Lefferts Place, Brooklyn, N. Y	Samuel Sheldon. Aug. Treadwell Jr. Douglass Burnett.
WISE, JOHN SHREEVE, JR.,	Electrician The Pa. Mfg. Light and Power Co., residence, 2023 Mt. Vernon St., Philadelphia, Pa.	J. H. Vail. A. E. Winchester. H. T. Hartman.

Total 11.

The following named associate was transferred to full membership.

Approved by Board of Examiners, January 18th, 1899.

GEORGE T. HANCHETT, Electrical and Technical Engineer, 123 Liberty Street, New York.

The following paper on storage batteries and railway power stations was then read by Mr. Robert McA. Lloyd.

A Paper presented at the 132d Meeting of the American Institute of Electrical Engineers, New York, President Kennelly in the Chair; and Chicago, Local Honorary Secretary Pierce, in the Chair, February 15th, 1899.

STORAGE BATTERIES AND RAILWAY POWER STATIONS.

BY ROBERT MC A. LLOYD.

A difficulty confronting us is that very few operators of railway power stations have any data showing what they are doing. Electric light managers seem to take more interest in the output of their stations, and in many cases maintain a system of records of work done, but the manager of a trolley road is usually contented with superficial observations of the switch-board and the comforting fact that the cars are running.

We always find these managers greatly surprised when the actual state of affairs is shown to them on paper, and I believe that this INSTITUTE would be astonished at the results of a thorough research into the load curves of the railway plants of the entire country. You are of course prepared for the statement that the average load on a railway power station for a given period is much less than the maximum load occurring during that period and much more than the minimum, but it is not generally understood that the maximum load for the same period is apt to be far below the capacity of the generating plant in operation. As an illustration of this fact I show in Fig. 1 some data on a typical railway plant when 35 cars were running. We have not discovered any railway plant where this is not true, and I believe that the data on most of the railway plants of this country will confirm my statement. The first explanation of this would be that such a surplus capacity is necessary for reserve to meet emergencies, but I do not find it to be a useful reserve, and

shall refer particularly to Fig. 1, taking this station because from the standpoint of the manager, engineers and attendants it is dangerously overloaded, and has no reserve. In fact it was necessary to add to the capacity at once to make it safely operative.

I obtained these data on the day of heaviest travel in the whole year. It will be noticed that the highest point reached was within the capacity of the main station, and yet it was necessary to start up an auxiliary station. The central solid line shows the average load, and the upper and lower lines show the limits of the fluctuations occurring from moment to moment. The method pursued in getting these curves was to divide the day into half hours, and during the first five minutes of each half hour take the highest and lowest ammeter reading in each minute; these readings are plotted in the upper and lower curves; also to take ammeter readings every five seconds and obtain the average of these readings as the point in the curve of averages. Another convenient method of obtaining the curve of averages is by wattmeter readings. Among some of the interesting features in this diagram may be noticed the fact that the nominal capacity of the generating apparatus was about 400 K w. in excess of its maximum output occuring at about 8 o'clock in the evening, and that the average output at this time was about two-thirds of the maximum. The excess of nominal capacity was not so great at 7 o'clock in the morning, or two in the afternoon when other high points occurred, but as it was known that the morning peak would be of short duration, the engineer decided to run through it without the auxiliary station, and in the afternoon the load increased more rapidly than was expected, and the auxiliary was not ready to go into operation on short notice, consequently obliging the main station to groan under a dangerous load for an hour or so.

It will doubtless occur to some that this station apparatus has been over rated, or that the engineer was incapable, or over cautious, but the fact remains that similar data are obtained in very many stations, and that in many cases the apparatus has been subjected to satisfactory tests before acceptance by the purchasers. It may be possible to build engines which regulate at all conditions of load and at the same time use steam satisfactorily at maximum load, but I do not find such engines commonly in

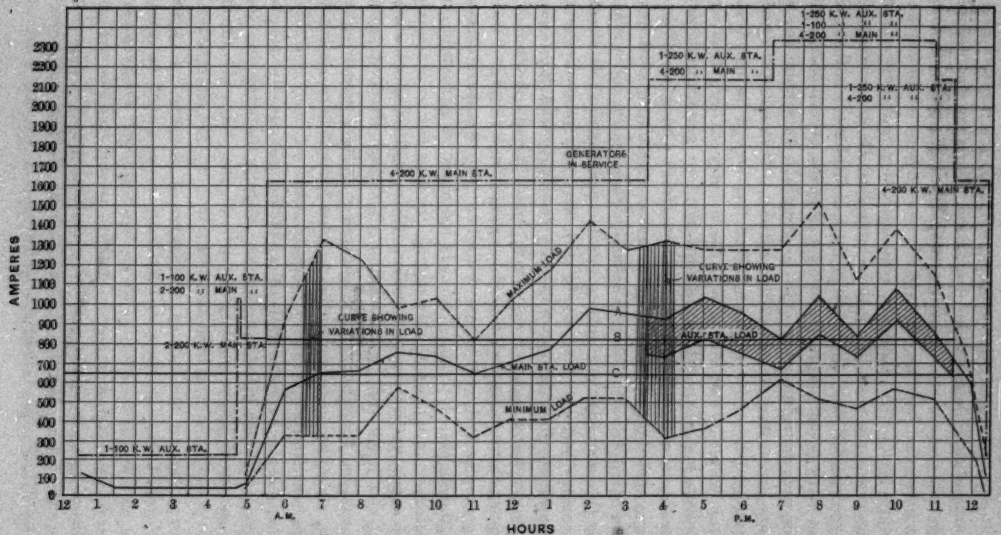

FIG. 1.—Curves showing variation of special Saturday load, August 20th, 1898.

use. Further than this there are many very good engines in use which cannot be safely operated at anything like maximum load if that load is liable to sudden variations. I realize that you may suggest all sorts of schemes for getting a better output from the plant illustrated by this curve, and you may wish to ask some questions about this apparatus, but experience convinces me that the men who are most likely to be consulted about such a station will recommend more generating plant, and the truth is that there are so many good salesmen pushing engines and dynamos that station managers frequently fail to get full duty from the machinery which they are operating already. It is not merely that the storage battery has been neglected, but any of us can see in railway power-houses throughout the country, where the managers have been persuaded to increase their generating plant, when attention to a few details such as steam piping would have brought their output up to requirements. Assuming however a station equipped with the best obtainable apparatus, and operated under the most advanced laws of station practice, in the absence of a storage battery, there would still be much more apparatus running than would appear necessary from the load diagrams.

The generator salesman says in reply to this proposition that his apparatus is cheap, and that it is good to have plenty of it, but one generally finds that where there is plenty of apparatus available, the engineer is tempted to keep too much of it running, and therefore running at low efficiency.

Of course railway power stations have individual characteristics, and it will not do to assume that they all need storage batteries, but there are certain features of railway power requirement, which are common to the problem everywhere, and which invite consideration for the storage battery.

The curve characteristics of electric light supply are well known, and much information about electric lighting has been brought out in the committee reports of the National Electric Light Association for 1896 and 1897, and by Mr. Hammond in his paper before the British *Institution of Electrical Engineers* in March, 1898, but the possibilities are more varied in railway work, and as far as I know, there has yet been no systematic research into the economy of railway power stations, the only published data on the subject being contained in the paper read before the Street Railway Convention at Boston last September by Mr. R. W. Conant.

In my endeavor to point out some of the uses for a storage battery, I shall take as a typical station that shown in Fig. 1. It is located in a Pennsylvania town of 50,000 inhabitants. The railways radiate from the center of the town to distances of three to nine miles. There are six branches, and the power station is located two miles out on the longest branch. It has railroad and water frontage. The small auxiliary power-house is the result of a recent consolidation and is close to the main house. There are three distinct ways of using a storage battery with this power plant. Taking up the figure we find first the great fluctuation between night and day load; second by the fluctuations occurring from hour to hour; and lastly the superimposed fluctuations occurring from moment to moment. We shall call a battery of sufficient capacity to level off the night and day fluctuations "large"; a battery for leveling the hour to hour fluctuations "medium"; and a battery to level the momentary fluctuations "small." It will be seen at a glance that the small battery will reduce the requirements of the generating plant to a capacity sufficient to meet the demands of the average load shown in curve A. The battery must be able to discharge at 650 amperes for momentary periods, but its capacity in ampere hours is unimportant. It will cost less than generating capacity for the same work, and a large part of the excess of capacity over requirements shown in the diagram will be saved. It will save some depreciation on the generating apparatus, and its own depreciation will not cost more than the depreciation of generating apparatus of similar capacity. It will have sufficient storage capacity to run a few night cars and lights, when the engines are shut down. If located at a point nearer the center of feeder distribution than the location of the generating station, a saving in copper will be effected. Inasmuch as the investment will not be increased by including such a battery in this railway outfit, all the saving in fuel due to a steadier load and the operation of less generating machinery will be clear gain to the credit of the battery.

Line B at 810 amperes shows the average load for 18 hours of the day, and a "medium" battery to reduce the load to this straight line would have a capacity of 1300 ampere hours. It will cost about twice as much as a "small" battery, but will not add enough to the cost of the installation to bring the investment up to the total now in generating apparatus alone, and presum-

ably necessary if no battery is used. This battery will have all the advantages of the small plant with wider limits of operation. The station circuit breakers may be set 650 amperes higher, and there will be greater convenience throughout the station in operating at a fixed load. There will be a marked effect on the efficiency of all departments of the station, and all the apparatus will yield a higher output in proportion to investment and cost of operation.

Line c at 650 amperes shows the average load for 24 hours, and a "large" battery capable of leveling off this load will have a capacity of 3000 ampere-hours. It will cost approximately twice as much as the "medium" battery and will have all of its advantages. It will cost as much as the generating machinery displaced by it. It will add largely to the flexibility of the station. This battery could be discharged momentarily at 3000 amperes, which will put the circuit breaker limit of the station at about 3600 amperes instead of 2300 with all the present apparatus. It may be discharged at 1500 amperes for one hour which will be sufficient to cover load peaks that would stall the 1150 K.W. generating plant completely.

In cases of extreme necessity the entire system might be carried by this battery for several hours. The ability to carry sharp peaks is a distinct addition to the earning power of the system. Such peaks often signify the collection of fares which would be lost if the system were not flexible, and some managers keep up enough station capacity to carry a few holiday crowds while for 99% of the whole year it is earning nothing. Other managers do not attempt to carry special crowds. The large battery will give the manager an opportunity to get all the money that can be made out of such business without feeling that he has made any investment for the purpose. Of course the capacity of the system is limited also by the investment in copper, but in many cases the battery may be located so as to facilitate the distribution of power.

There is no reason why a railway power station of this capacity running night and day at a constant load should not attain a fuel economy as high as that of the well-known Chestnut Hill Pumping Station at Boston which would be equivalent in electrical work to 557 watt-hours per pound of coal. Curve A, Fig. 1, shows for 1 days work 7,800,000 watt-hours which required at the above rate 7 tons of coal, and assuming that the battery

would only have 75% efficiency, and that 25% of the entire day's work would go through the battery, ½ ton of coal would be added to this consumption, making 7½ tons of coal per day for this plant running with a large battery.

The battery efficiency in such service as this has been found in most cases much higher than 75%, and in some cases over 90%, so my estimate is clearly on the safe side.

On the day when these data were obtained 15 tons of coal were burned, or twice as much as would be necessary with the battery outfit. The battery would therefore save at $2.00 a ton, $5,474.00 per annum in coal alone.

The number of men in the station is now the same night and day, and there would certainly be no increase in the labor item, whereas it is probable that one man on each shift might be dispensed with if the plant were reduced by the battery, in which case there would be another saving of $1,200 per annum. The battery would also save water, oil, waste etc., and there would be minor advantages such as more constant potential on the line; less annoyance from circuit breakers; no fear of sudden demands on the generating apparatus, and the disagreeable possibilities incident thereto.

In the following table some figures are tabulated for the purpose of comparing four different layouts to meet the requirements of the railway system referred to in Fig. 1.

TABLE REFERRING TO FIG. 1.

	Lay out with	Cost of generating apparatus	Cost of Storage Battery	total cost of station plant.	Cost of Coal per day	Cost of Coal per annum	Saving in Coal	Saving in coal and saving in int. 5 p.c.
1	No battery	$115,000	$	$115,000	$30	$10,950	$	$
2	Small Battery	60,000	20,000	80,000	25	9,125	1,825	3,575
3	Medium "	50,000	35,000	85,000	20	7,300	3,650	5,150
4	Large "	40,000	70,000	110,000	15	5,475	5,475	5,525

CONTINUATION OF TABLE.

	Cost of Real Estate and Buildings.	Repairs and Depreciation	Saving in Labor per annum.	Saving in water, oil, waste, etc.,	Total Saving	Estimated Addition to receipts.	Net Advantage in operation
1				$	$	$	$
2	All the same	All the same		100	3,675		3,675
3				200	5,350	1,000	6,350
4			$1,200	300	7,025	5,000	12,025

I have assumed $100 per kilowatt as the cost of complete station apparatus without batteries. This figure might have seemed high a year ago but in view of the rising prices of such material I think it is only conservative.

In regard to the "small" battery, there is no doubt of its advantages in many cases, but for new installations it is not always the most economical battery. I understand that Mr. Leslie Carter, the President of the South Side Elevated Railroad Co. in Chicago, said recently, that as far as he knew, their battery did not save anything in the cost of operating the road, but that they could not run without it, and I take the liberty of making the following extract from his annual report to the stockholders which has since been published.

STORAGE BATTERIES.

"While the amount of current used per car mile is low, and has produced gratifying results in all tests and comparisons made, the fluctuations of power above the average requirements are large, and the sudden demands on the power-house compelled us to prepare promptly for the heavier business of the winter, which, with increased number of cars in service, heat, and light loads, would have been beyond the capacity of the power-house. Additional engine capacity could not be obtained in the time at our disposal, would have cost more money, and have been expensive to operate. We accordingly installed two batteries of 750 K.W. each, equidistant from the power-house, at Twelfth and Sixty-First streets, respectively. These batteries have greatly reduced the fluctuations and the maximum load at the power-house. While the output at the power-house is the same, the batteries charge at times of light traffic and discharge at times of heavy traffic, thus equalizing the work at the power-house, and relieving the engines and generators. This is certainly an economy, and it is further claimed, with what correctness I am not yet convinced, that they cheapen the cost of production. But I do know that they keep up the voltage at the ends of the line, enable your road to operate more cars, furnish increased facilities to patrons, and prevent damage to power-house machinery in case of sudden demand for increased power."

That battery was of course put in for regulating purposes only, and the load curves some of which are shown in the following figures give one the impression that the battery must certainly be useful. It seems to me hardly worth while in laying out a new station to put in a battery for the purpose of reducing the railway power curve to the characteristics of electric light practice, when by going a few steps further it may be refined to a practice comparable with marine engineering.

It might appear at first thought that a battery of sufficient capacity to ensure a full load for the generating units at all times, would save as much fuel as a battery large enough to level off the 24-hour service, but it is very difficult to follow the power requirements from hour to hour in such a way as to make ideal use of a battery, whereas with a "large" battery it would be possible for the ordinary station engineer to adjust his load so as to operate all of his apparatus to the best advantage all the time.

I have carefully analyzed the figures in Mr. Conant's very interesting paper above referred to, and am compelled to differ from him at some points, and refer to them in order to meet in advance any criticism of my paper which may be based on his tables. In the first place he assumes that his standard station can be worked all the year round with a load factor of 33⅓% which is entirely too high: 20% or 25% would be more normal. I suspect that Mr. Conant's load factors have been obtained by indicator cards instead of wattmeters. In Mr. Conant's table none of the stations show a better figure for coal than 3 pounds per kilowatt hour while his standard station is put down for 2.2 pounds without any intimation of the process for attaining such a good result. The question as to how the cost of repairs and depreciation of the entire plant would be affected by a large battery is particularly debatable ground. Mr. Conant allows 2% for depreciation beyond the normal running repairs. He estimates the entire plant including buildings to last 50 years. His statement that the machinery now being installed will last much longer than that with which we have been familiar in the last decade has nothing to back it up except faith in the promises of the builders.

I propose to allow 10% per annum for repairs and depreciation, on the entire station apparatus, including batteries. I have not seen any boilers that are likely to last 50 years, and there is plenty of evidence that all the best engines and boilers in this class of service to-day will go to pieces in a life of from 10 to 20 years. The particularly hard usage to which most of them are subject is not only steadily wearing them out, but producing a state of constant damger and not infrequent accidents. I am sure this is becoming well understood among railway men, and some of the best managers are writing off to depreciation 10% per annum. Moreover who can say that improvements will not be made in the next 10 years as in the past, and that engines and boilers may not be out of date before they are used up.

It is of course well known that whatever the rate of depreciation may be without batteries, it will be lowered by giving the generating apparatus a constant load; my belief is therefore that the storage battery will not increase the rate of depreciation for the entire plant. If it can be shown that interest and depreciation for a plant of given load dimensions are practically equal with or without a large battery, it is evident that the great saving in fuel alone will determine the superiority of the battery system.

I have so far considered the battery only at the central generating station, so that all the advantages due to locating it at proper points in the distribution system are additional arguments in its favor. In many cases the saving in copper may be greater than the sum invested in the battery, and the flexibility of the system improved in places where it would not pay to install sufficient copper to meet the irregular demands of travel.

The reserve qualities of the storage battery are unique. It might be supposed that a mere reservoir which is quickly drained would be of little value compared to a lot of extra generating apparatus standing idle, but experience is demonstrating every day in existing plants, that the reserve which is needed most is the reserve which is not only ready for emergencies, but actually alive to any demand without the direction of a human mind.

Most of what has been said of the storage battery as applied to the power station illustrated by the curves in Fig. 1, is true of its application to railway power stations in general. The use of water power introduces a factor in the problem more variable than fuel, and I shall not attempt the discussion of it. Alternating currents lend themselves readily to the development of storage battery applications on account of the mutually helpful combination of battery and rotary at sub-stations. Up to the present time, each of the large batteries installed for railway work has been obliged to meet different conditions, and requirements, but they are all serving their respective purposes well, and showing many different fields of usefulness. I shall not refer to these plants because Mr. Appleton in a recent lecture to the *New York Electrical Society* has ably described those of most importance.

Most of us feel that the electric railway and electric lighting interests are destined to get into closer relations, and the generating station of the future may be required to furnish all the electricity used within large areas for every purpose.

Coming finally to a problem which has been the subject of some newspaper discussion of late, I trust you will pardon me for treating of work with which I have no connection. Electricity has so many advantages over any other medium for transmission and storage of energy that I assume its use to be firmly established and cannot conceive of any lasting rivalry by the other contestants now in the same fields. Further than this without saying anything for or against monopolies, I believe that all the energy supplied by means of electric currents to consumers of every nature in the greater New York should radiate from two or three central stations, and that these should be electrically tied together. The sub-stations would naturally consist of rotaries and storage batteries. It may not be possible to lay out each sub-station so that the rotaries would run at a constant load for 24 hours a day, but it seems to me quite probable that such an arrangement would eventually be reached, and this would of course give the generating stations a constant load.

At the present time the load curves of the electric railways are very uncertain, and peaks are likely to occur at almost any time of day, while the addition of the peak due to electric lighting in the early evening would not add in large proportion to the railway peak, but electric lighting is capable of more general application and it is possible that within a few years the distribution in the Borough of Manhattan may reach from three to five hundred thousand kilowatts at the highest part of the lighting curve, which will probably be as great as the railway load when the elevated railway and the underground rapid transit are included. These peaks will often occur at the same time of day, and so there is no possibility of improving the load factor of either system by splicing the two together. It follows therefore that what is true of the relation of a storage battery to the economy of the generating station for power or light separately will be true of the resultant of their combination.

The railway and light people recognize the importance of leveling up some portions of their load curves, but I estimate that the greatest saving is to be obtained by operating for a constant load 24 hours per day. However high would be the economy of such large stations I am sure it would be higher with large batteries than without. Certainly the economy of the Boston pumping station as to fuel consumption should be surpassed. It must not be assumed that a high load factor for the system is

an advantage. It is all right for the generating plant and for the copper feeders, but the kilowatt hours that bring in the most money, may spoil the looks of the load diagrams and kill the load factor. What is required to earn dividends is a *profitable* load factor outside of the stations, whether high or low, and the highest possible load factor at the dynamo terminals. The large storage battery meets these two requirements perfectly. A load factor of 100% may be maintained at the dynamo and current may be sold to the consumer regardless of the time of day.

With a million kilowatts in view for the Borough of Manhattan it would be necessary to generate an approximately constant force of 300,000 kilowatts.

A million kilowatts in station plant without the battery factor would cost $100,000,000.

The same capacity including the proportion of battery now deemed advantageous by some of the engineers in touch with these problems would be divided as to cost into $70,000,000 of generating plant and $30,000,000 of battery plant.

Finally the same capacity if divided in the proportions which seem to me most productive for the investment would cost $30,000,000 in generating plant and $70,000,000 in battery.

This is quite a large battery plant and as there would be more than two parts battery to one part generator, I am fearful of the jealousy which such a reversal of engineering practice would create.

In conclusion I wish to state that nothing in this paper should be regarded as emanating officially or unofficially from the company with which I am connected.

The following figures show a number of railway power curves with and without batteries. If they do not indicate attainment of perfect results by the battery, it is not because perfect regulation is impossible, but because the engineer is well pleased with what he has, and does not strive for greater refinement. Fig. 2 shows the application of storage batteries to a large rail way installation in which part of the power is generated at a waterfall. It shows what may be done by what I have called a "medium" battery.

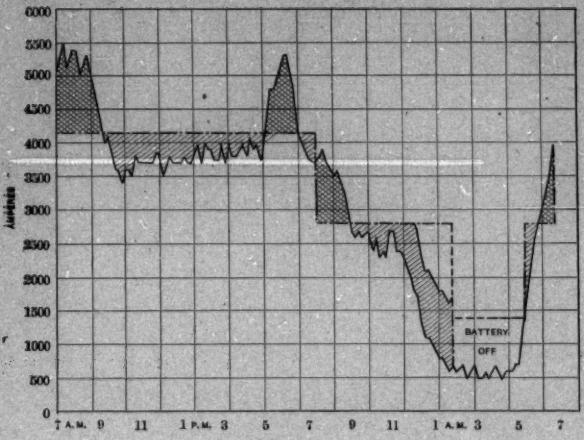

FIG. 2.

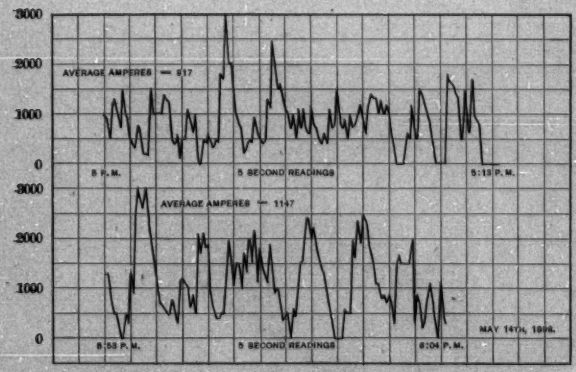

FIG. 3.—Curves showing Fluctuation of Load, May 2d, 1898, at Power Station of South Side Elevated R. R. Co., Chicago, Ill.

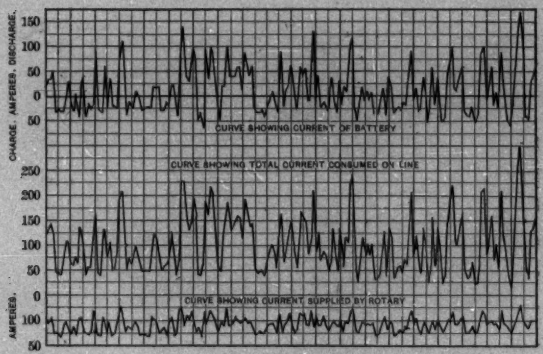

FIG. 4.—Curves showing Regulating Effect of Storage Battery, at Power Plant of the Barre, Montpelier Traction Co., Montpelier, Vt.

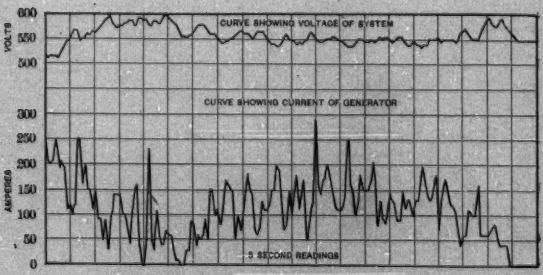

FIG. 5.—Tests made at the Woonsocket Electric Machine and Power Co. Generator carries the whole load of station. Barber Regulation.

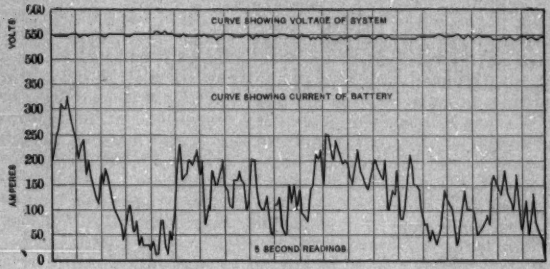

FIG. 6.—Tests made at the Woonsocket Electric Machine and Power Co. Battery carries the whole load of Station.

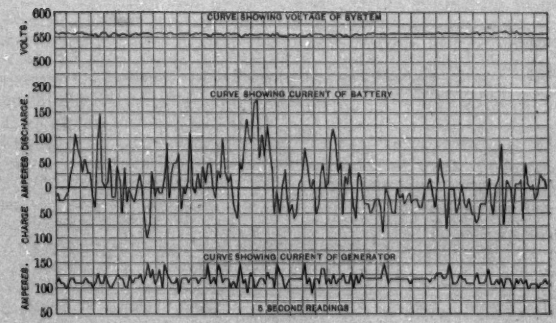

FIG. 7.—Test made at the Woonsocket Electric Machine and Power Co. Generator and Battery in operation.

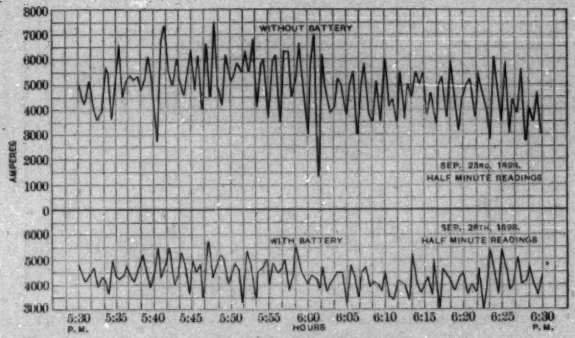

FIG. 8.—Curves showing Generator Load at the Power Station of the South Side Elevated Railway Co., Chicago, Ill.

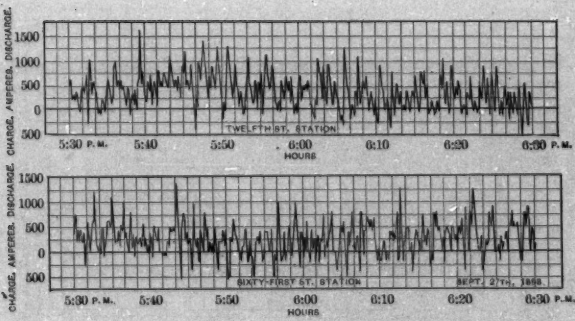

FIG. 9.—Curves showing Regulating Effects of Batteries at the 12th St. and 61st St. stations of the South Side Elevated Railway Co., Chicago, Sept. 20th, 1898.

Discussion in New York.

The President:—The paper to which we have just listened is now before the Institute for discussion. The discussion ought to be interesting—fully as interesting as the paper has been, because there is set forth in the paper a proposition which seems at first sight a very radical one, and that is to have a battery in a power station costing more than twice as much as the steam plant. The question as to what proportion should exist between the generating system and the storage system in a central station, is a very important one from an engineering and a commercial point of view. The usual plan has been to regard the storage system as a relatively small and auxiliary part of the generating plant. In this paper, however, the proposed plan is to make the storage battery the principal element. The paper is now before the meeting for discussion.

Mr. George Hill:—Although I am not in the street railway field, I have done a little in the line of storage batteries, and my criticism of the paper would be that the point which you emphasize, Mr. President, as being worthy of discussion, has not been sufficiently emphasized by the author of the paper. I would go much further and be much stronger in my advocacy of a large storage battery than he has been under the conditions given. I have had an experience extending over nearly three years with a storage battery installation designed by myself for an office building here in New York, in which the storage battery cost I think, a little over four times as much as the generating plant. The installation was in a building 75 feet by 100 feet, six stories high. The ordinary fuel consumption in such a building would be from 300 to 450 tons per annum. The fuel consumption in this building is an average of 118 tons per annum. The installation, I think, was the first one of the kind in which no attempt was made to load the engine other than with the storage battery. In other words, it was the first attempt to give the engine a uniform load throughout its period of work. I figured carefully the requirements of the building, and installed two complete sets of cells, each one having an ampere-hour capacity sufficient to handle the entire building for at least fifteen hours. At the start we found that we had sufficient capacity to handle the building for two and a half ordinary days. Later on, as the building filled up, we found that we had, and we now have, capacity to handle the building one and one-half ordinary days, or easily through the heaviest day that we have ever had.

The entire apparatus is of the simplest possible description. The switchboard simply contains the recording instruments with duplicate generator and battery switches; simply two double-throw two-pole switches, so arranged that when the handles are on the same side, one set of cells is discharging, and the other set of cells is being charged. In the morning, when the engineer

starts up his plant, he simply transfers the two switches so that the handles are both on the opposite side, and the cell that was charged the preceding day is discharged, and the exhausted cells are again charged.

At the time, the storage battery company from which I purchased the plant did not understand why we were squandering so much money for storage batteries. In order to relieve their anxiety I went over the relative cost of the engine, generator, booster, various regulating rheostats and automatic devices, and we found that the additional cost would not exceed a thousand dollars, or about the annual cost of the additional fuel due to the fact that there the generator would not run at a constantly economical load. The operating economy of that plant is phenomenal, as 118 tons of coal furnish all the light, heat, elevator service, pumping, fan service and every other requirement of light, heat or power in the building. Commercially considered, we

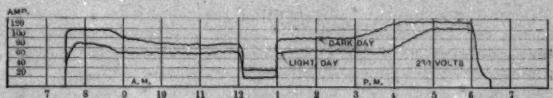

Fig. 2

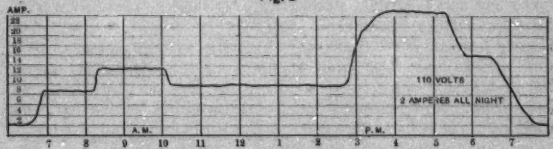

Fig. 1

expended about $4,000 more than the usual plant would have cost, and saved the interest on $11,000—a net saving of about $420.00 per annum. The load curve is like Fig 1. For pumps, lights, etc., the elevator duty would show as a fringe of vertical lines of 60 amperes, one for each minute from 8:45 A. M. to 5:45 P. M.

On the other hand with a load curve like Fig. 2, which is taken from a manufacturing building designed by me operated with a direct connected 50 K. W. generator, the load comes from four electric elevators of good speed and large capacity; 75 horse-power of motors and 300 lamps. The load ranges at about 17 K. W. with frequent fluctuations up to about 66 K. W., and a few drops to 11 K. W. The total monthly output is 9,000 K. W. hours; the coal consumption for the generator, pumps and for live steam to various heating appliances in the building, paste making, etc., is about 170 lbs. per hour in

the summer, and about 200 lbs. per hour during the severe weather in the winter. The curve shown is the light and motor curve the elevators would add to it a fringe of vertical lines, two per minute from 7:30 A. M. to 6:15 P. M. 75 per cent. adding 45 amperes and 25 per cent. adding 90 amperes. If we then figure the annual coal consumption for the building on the basis of 3,000 hours per annum we will have

2,500 hours at 170 lbs. equal 425,000 lbs.
500 " " 200 " " 100,000 "
" 234 tons equal $610.00.

If we try to perform the service with storage batteries and install them under the most favorable circumstances we will have 33 K. W. per hour. Assume that our engine can be installed so as to take no more than 1½ lbs. of coal per brake horse power, that our generator has an efficiency of 90 per cent. and our storage batteries an efficiency of 85 per cent. This means an hourly coal consumption of 84 lbs., then fuel would figure

2,000 hours at 84 lbs. equals 168,000 lbs.
500 " " 170 " " 85,000 "
500 " " 200 " " 100,000 "
" 157½ tons equals $410.00.

The saving of $200 capitalized at six per cent. would be $3,333 or manifestly insufficient to pay for the additional cost of the more economical engine with its condensers, etc., leaving nothing for the storage batteries.

Every plant must be considered on its merits, and the use of one or two systems decided on according to the requirements of the case. One system being the direct generation of current in which the engine should be proportioned to work at rated capacity with $\frac{3}{16}$ cut-off being of a simple high-speed type, and operating normally under a pressure of 90 lbs. but with the parts so proportioned as to transmit easily a 30 per cent. overload, the speed being maintained by a much later cut-off and increase in pressure. The generators should be of the heavy design generally met with in present practice with wide non-sparking range, carbon brushes and with very low current density in the parts. The K. W. capacity should be so determined that the momentary peaks shall produce overloads up to 40 per cent. The other alternative would be the generation of current in a compound, condensing, direct connected plant with high steam pressures. All of the current stored in duplicate sets of cells each one equal to one day's discharge, and the plant operated with one set of cells being charged while the other was discharged. The engine running from 12 to 24 hour shifts and loaded continuously to its most economical point. It is my belief that where storage batteries can not be shown to be economical under these circumstances they have no place at all in new installations. It is of course necessary in any plant to insist that it be operated in the manner in which it was designed to operate. There are no

doubt many cases in existing plants where storage batteries can be advantageously used, but they are special cases for which no general rule can be laid down.

The point mentioned in the beginning of the paper in regard to excessive kilowatt capacity installed, as compared with the actual output leads me to imagine that the central station engineers are meeting some of the difficulties that I experienced eight years ago when first calling for engines to supply light and power to buildings. That is, all parts too light.

It may be interesting to state, in connection with the item of depreciation, that my experience with the storage battery plant before mentioned, shows that if the plant is in charge of a competent engineer, depreciation can be neglected. In the three years that this storage battery has been in operation we have expended certainly not five dollars, the chief engineer tells me nothing—for renewals or repairs, and I believe that the cells are in better shape to-day than when they were first put in, and from their nature should not depreciate. It is necessary, however, in order to give the engineer a chance, to so design the plate connections and from them to the 'bus bars of the switchboards, that each plate shall have practically the same amount of resistance. The details furnished to us to make this installation I found thoroughly unsatisfactory and so changed them materially, and to this I attribute much of the successful operation of the plant. Of course the engineer understood his business thoroughly and carefully watched every plate so that there was no chance for them to run down. It would be unreasonable to expect that all engineers would be as careful, and we must make some allowance for depreciation due to this cause. It may also be desirable to make some allowance for depreciation due to improved methods of manufacture, but generally, I think it fair to say that the depreciation of a properly designed and properly handled battery plant should be insignificant.

Mr. C. O. Mailloux:—This paper is a complete statement of all the salient features and advantages of the storage battery as a factor of economy in central station practice, and it gives all the principal points which the engineer should take into consideration in designing a plant wherein he intends to utilize storage batteries. I agree very fully with all the statements made by our colleague Mr. Lloyd, and I particularly appreciate the stress which he lays upon the preponderance of the storage battery. I use the word preponderance because the importance which he ascribes to the proportion of the storage battery seems like a preponderance to those engineers who are not familiar with the advantages of the storage battery, and who are still skeptical or conservative in its use. I have had occasion to utilize batteries myself, and the practical results have indicated very clearly that the principles enunciated by Mr. Lloyd are correct, and that they can be demonstrated by actual practical results. The diffi-

culty has been to make people realize the possibility of this. As you know, the time was, and it has not been far back, when the word storage battery was a very dangerous one to use by any one who wished to retain the respect of his colleagues in the electrical engineering fraternity. I am one of the unfortunates who have had to suffer the result of my misguided, early, pioneer, zeal in that direction. The rapid growth of the storage battery in the last three years is a circumstance of great satisfaction to such as myself, who had to bear the jeers and taunts of derision in years past.

There is one point which the last speaker referred to, namely, the point of depreciation, which I think ought to be carefully considered. My own experience with storage batteries covers a period of at least ten years, during which time I have seen batteries come and go—mostly go; and, in spite of the fact that I have great faith in storage batteries, having always been an apostle of their use—I cannot quite concede the propriety of the statement that no allowance, or at least only very small allowance, need be made for the depreciation of storage batteries. A battery may, indeed, work quite well for the first year, the first two years, the first three years; I have seen them work five years, under conditions where they require little or no allowance for depreciation. But I think it is an error to believe that because it is postponed five years, the day of reckoning is not going to come, because it certainly will come; and I think that the careful engineer should not mislead—his zeal must not mislead him to the extent that he must not make a fair and due provision for that day of reckoning. Good engineering practice dictates that one should make an allowance for a certain item or percentage of depreciation of the storage battery just as one would on other things, I have myself found that it inspires confidence in a man who has been hitherto a skeptic on this subject, to tell him frankly that he must allow 10 per cent. for depreciation of the storage battery, because when he finds, later on, that it is only costing him six or seven per cent. to maintain his battery during a period of ten years, he has more respect for both the engineer and the storage battery; whereas, if he had been told that it would take little or nothing, and he afterwards discovered that it did take as much to maintain it as the rest of the plant, he would not have felt so well about it.

A singular instance of this has occurred in my own practice. I installed a plant in connection with a storage battery some four or five years ago in an office building. I think it was the first office building in New York city in which storage batteries were introduced. The principal reason, and perhaps the only excuse at that time for their introduction was the necessity of making provision for lighting at night, as the offices were occupied by tenants who at times did night work, and must have electric light. It was sought to make arrangements with the street light-

ing companies for a so-called "breakdown" connection or supplementary supply to be used at night; but the terms exacted were not deemed satisfactory to the owner, and he finally seems to have lost his temper and to have decided that he would allow such a reckless thing to be done as to put in a storage battery, although he evidently looked upon it more in the light of a necessary evil, or something that one could do, perhaps, to spite someone else, rather than because he was actuated by motives of economy or good engineering. I remember frankly stating to him that the storage battery was not to be regarded as a luxury, even though I believed it to be practicable in this case; but that its use involved certain losses and expenses and that he must face the possibilities, some of which might not be reassuring. I did this for several reasons: First, because I was none too sure myself as to the future and the possibilities of storage battery maintenance, and secondly, because I wished to disappoint him agreeably if at all. The figures of estimated annual costs which I presented to him seemed rather large although they still were less than what he had been paying for current. He finally decided to adopt the storage battery. He had misgivings as to whether the percentages guaranteed could be maintained, etc. After the plant had been in operation about two years, I went to this gentleman to get figures in regard to the economic results. The gentleman hesitated greatly, and finally said that he did not care to give me any statement. He would simply state for my information that not only had I met all the promises which I made to him, but that the results had been so much more satisfactory that he had respect for my modesty and did not wish to strain it by making me feel too good. This case illustrates the importance of not deceiving the client, or rather of misleading him by being too zealous or having too much faith in yourself. I feel quite certain that if I had understated what he might be expected to pay for the depreciation of the storage battery he would not have given me such a complimentary report, and probably would have been very glad to show me the figures after two years, and to have "rubbed them into me," so to speak.

It is, perhaps, to be regretted that the author did not elaborate a little more fully those explanations and calculations on which the conclusions are based. There is no doubt that the facts as stated are correct, and that the principles on which they are based are also correct. Nevertheless, to those not thoroughly familiar with the subject, and especially to those who are at all inclined to be skeptical, a little more detailed information regarding the reasoning on which the results are based would have been of interest, for example, some figures showing a little more fully than is shown in the tables, of cost, the manner in which the advantages vary with the size of the battery, or the proportion between battery and electric generator plant.

The plan mentioned by the last speaker, of utilizing the cur-

rent entirely from the battery, may have its advantages in some cases; though its utility, especially in large installations, would seem to be more doubtful. In large installations it is necessary to run machinery for generating energy for such a large proportion of the 24 hours, that the equipment might just as well be arranged in such a manner that a great percentage of the energy would be utilized or fed into the feeders direct, instead of into or through the battery. In this way the economy of the plant is increased, and one is enabled to secure better conditions of economy with a smaller total initial cost. As for the annual cost of operation, I think there can be no doubt that it would be very much smaller with proportions such as are advocated by Mr. Lloyd.

There may be, of course, advantages incidental to one plant or to another which dictate its adoption, because they may become considerations of peremptory and paramount importance in special cases. But in the absence of such arbitrary considerations, it seems to me that those conditions which produce both the highest load factor and the best economy in the generating plant, are generally apt to be those conditions which lend themselves to the least total yearly cost for the total energy output per annum.

Mr. E. T. Birdsall:—For the past few years I have been following this practice as closely as I know how in railroad plants that I have built. I have used the battery both as a pressure equalizer and also as a load equalizer in the station, and with very good results, and I think it has only needed a battery that we could rely on for everybody to fall in line in this same practice. Its benefits and advantages are self-evident, especially in lighting plants. All we have to do is to look at the gas companies and see how they operate. They do not need any two-rate meters or any maximum demand meters or anything like that to charge for gas, and they appear to make money. They make their gas right along, 24 hours a day, and put it into a reservoir. Of course, storage batteries cost more than gasholders, although not so very much more, and I think lighting companies will gradually come to the point where they will pump the electricity into a big battery and let the customer use it as he pleases. Of course I realize that a customer who uses his current at the same time that everybody else does, makes the station buy a little more battery, but it is not as bad as boilers and engines, and it is better for the economy of the station.

In regard to Mr. Lloyd's first paragraph, I think that is the truest thing I have heard in a long time. I have recently been through all the railway plants in a large city, some seven of them, and I think the reason that most railroad plants have more capacity than they need, and run more engines and dynamos every hour than the load requires, is because the engineers like to have an easy time. As a rule you will find the engineer in a large

power-house has a nice room which is comfortable and warm and free from dust, or a fine raised platform with a shining brass railing around it, and he likes to sit there and read the technical journals and have a chat with his friends. If he had to go out every few minutes and close circuit breakers that would not be comfortable, and he does not propose to do it. It is so much easier to tell the man to start up another engine and dynamo. Although this may seem like a joke, I really think that it is the main reason. As I say, I have recently been through the stations and in every one of them—it was very snowy and cold outside the day that I went around—the chief engineer was having a very nice time in the station, and there were plenty of engines running inside the station, and very few cars outside. No circuit breakers opening and very few scars on the breakers. The great thing that most of these railroad companies need is a general engineer to go around and shut off engines. All these plants had plain Corliss non-condensing engines, and a number of them belted generators, about half of them were in wooden buildings and almost all the machinery was painted very elaborately. The amount of paint was something marvelous, and this was in a good sized city, about the fourth city in this country, and the coal—well, there was lots of coal—but all the companies were making money, and if the company makes money, why change? That is the great factor in boards of directors. I have encountered that several times myself. They say, this plant is earning 10 per cent; what better do we want? Why should we spend a lot of money and have more bonds and everything like that when this thing is good enough—what's the use? And those are the things that engineers have to contend with. It is against "good enough" and the engineer in the station who is having an easy time.

Mr. Mailloux:—There is another point which has been noted by Mr. Lloyd and which might be enlarged upon. It is the difference in economy of engines under varying loads. A very able paper on the "Performance of Street Railway Power Plants" was presented at Chicago in 1893, before the International Engineering Congress, by Messrs. W. A. Pike and T. W. Hugo, which contained some interesting data on this point. The authors called attention in their paper to the results of experiments with a certain engine, which plumes itself upon its ability to maintain a nearly constant efficiency line under wide variations of load. These experiments showed a difference of 30 per cent. between running on the fluctuating loads of the trolley line feeders, and running on a steady load obtained with artificial resistance, such as a water rheostat. In other words, the efficiency of the engine when measured by taking a large number of indicator cards while the engine was operating under fluctuating conditions, and taking the same engine running at the same mean load on a steady resistance showed a difference of about 30 per cent. [The exact steam consumption given by the authors was 29.2 lbs. for trolley

load, and 22.5 lbs. for steady load.] Now, if this is the result which is to be expected from an engine which is especially built to respond to such wide variations of load while retaining an approximately constant efficiency, one can surmise what will be the difference in efficiency when the engine is not specially built for such variations.

In connection with the matter of fluctuations, since we shall probably see more use made of storage batteries in future in large central station practice, I think it is well to begin to establish a notation. In a paper which I read on this same subject before the American Street Railway Association at Milwaukee in October, 1893, I endeavored to make a start in that direction by seeking to establish a distinction in the various kinds of fluctuations with which the storage battery has to deal as an equalizing factor. In other words, there are those variations which take place from hour to hour, a part of which occur in the peak of the load. To these I have thought that the name "variation" was more appropriate; whereas, those momentary and instantaneous fluctuations which take place from one instant to another might better be described and defined by the term "fluctuation." That is, the term fluctuation might better be restricted to those short and quick fluctuations, while the term variations could be retained for the longer ones which determine differences in the mean value of the load from hour to hour. To quote from the Milwaukee paper:

"I would use the term 'variation' to designate the effect caused on the station plant by putting on or taking off a certain number of cars; and the term 'fluctuation' to designate those incessant and erratic ebbs and flows of current which are so familiar to us all, due to the starting and stopping of cars, changes of speed, grades, etc. The variations of load are defined as changes, in mean or average rate of production for a given period of time; the fluctuations of load are defined as changes in rate of production from one instant to another. . . . . .

. . . . . The term fluctuation should, in my opinion, include both the 'waves' and the 'sub-waves,' while the term variation should be restricted to the 'billows.'"

Again, in dealing with a battery, we have to consider some of its features and peculiarities. We have to consider a battery from the standpoint of its total storage capacity, such as for instance, whether the battery is medium, large or small, as Mr. Lloyd puts it. It seems to me that a term would be necessary here, especially when we attempt, as we shall soon, to formulate the conditions and the principle under or by which a given size of battery is to be determined. All attempts at this formulation have failed hitherto, because there are still several unknown quantities in a storage battery—notably, the depreciation, or to put it more accurately, the rates of depreciation under varying conditions of service. We shall doubtless have abundant material on this subject in the course of a few years more, seeing the

rate at which storage battery installations are now being put up; and it will then be possible to formulate methods by means of which the best equipment can be determined just as perfectly and with as much ease as we now predetermine the details of a dynamo or a motor. Now, in doing this we shall have to consider, as I said before, certain peculiarities of the battery; one is its total storage capacity, to which I have given the term "quantity factor," and another is its rate capacity; that is to say, the ability of the battery to "give and take" energy, or the maximum rate which it can be called upon to deliver or absorb, for the purposes of load equalization in taking care of those changes which I term "fluctuations." I call this the "rate factor." Now we connect the rate factor with the fluctuation because it is the feature which is of utility in connection with the fluctuation, or the ripples in the load curve, and we connect the quantity factor with the variation, because it is that which is useful in the leveling out of the larger excrescences, or the "billows" in the load curve. As a matter of fact, the size and the cost of the storage battery, in a given case, depend mainly if not wholly, upon these two factors. Sometimes one of these factors, sometimes the other alone, and sometimes both together, will influence the size of the battery needed for a given case.

Extract from the Milwaukee paper:

"Your committee has found it convenient to designate these as the 'battery factors,' calling the first the battery 'quantity factor,' and the second the battery 'rate factor,' in which case they are expressed as ratios. Thus the quantity factor is defined as the ratio of the quantity of energy to be drawn from the battery, to the total quantity to be furnished to the (trolley) circuits under maximum conditions, while the rate factor is defined as the ratio of the current to be furnished by the battery to the total current, also under maximum conditions.

F. V. HENSHAW:—I would like to ask Mr. Lloyd whether in the figures for cost of storage battery given on page 65, anything is allowed for boosting apparatus or any dynamo-electric machinery for raising voltage in order to charge, or any allowance for switches for cutting in and out cells for regulating voltage in that way, or whether it simply includes the storage cells with their connections.

MR. LLOYD:—I might as well answer that now. I allowed the sum required for the entire storage battery installation and apparatus, and I just want to show you how simple that table is. The calculations are not as complicated as Mr. Mailloux might have given you to understand. The first three columns I got from the office of the storage battery company, which, of course, are available for everybody. As to the cost of coal per day; for number one plant with no battery, I took exactly what they were burning at this place—which was 15 tons at $2. For the large plant I took the standard of the Chestnut Hill

pumping station in Boston, which would have been 7½ tons, allowing for the loss in the storage battery, which you see only amounted to half a ton per day. So that even with a large storage battery, the loss due to the use of storage battery did not make very much of an addition to the total coal consumption. That was $15. The two figures in between, 25 and 20, I did have to guess at, to some extent, and yet I think that they are fair figures. The cost of coal per annum, next column, is figured from the last, and the saving in coal is also figured from the last, taking the very near station as the standard. I did not put the interest in a separate column, but of course you notice the difference in the investment in each case, and I simply added together the saving in interest over the No. 1 plant, and the saving in the cost of coal. I put down the same amount for investment in real estate and building, and allowed the same for repairs and depreciation, and I credited the large plant with a saving of one man on each shift in this particular station. There might be stations where that would not occur. In this particular one it would, because they had two firemen, whereas, with the smaller boilers running they could get along with one night and day. The saving in water, oil and waste I took from the engineer of the station himself, and the total saving is simply an addition of the others. The estimated addition to receipts I got from the manager of the road. He said if he could raise his circuit breakers as much as would be allowable with that medium size battery, he thought he could take in a thousand dollars a year more without any trouble, and if he had an additional flexibility due to the large battery he would take in five thousand dollars. Of course, the last column is the addition of the two former ones.

In regard to the cost of coal per day, of course I might have gone very deeply into that subject. But I ought to say that this station was a particularly economical one, as you will see if you will look up that curve and take $30 a day for coal, it is a very low cost. There are very few stations that could do that. The engines are compound condensing of the Corliss type and of high standard as to manufacture. The whole station was quite as good as you will find anywhere. At the present time these things are being put in perhaps a little bit better. But it was certainly good for the last few years. The economy was certainly fine on that day. The fact is, I do not suppose the average of the railway stations of the United States would come anywhere near that small coal consumption. Their coal consumption would probably be at least twice, and perhaps three times as great.

I have answered the first question. As to the estimated costs in column two. Those costs include everything except real estate.

While I am on my feet I want to say, in regard to the first speaker's criticism, that this is an extreme view of battery prac-

tice, I do not say that is the best one; it is one that occurs to me, and I know that a good many people do not agree with me, and it may not apply to all cases. It does apply in the station which I have especially studied. There is not any question there but that a large battery giving the opportunity for a more profitable use of current outside of the station, and more economical production of it inside the station, has advantages over either of the smaller installations of battery. It might not be so in the case of New York, although I think it is likely to be more so, because current between 5 and 8 o'clock in the afternoon in New York is wanted more than it is in the ordinary country town, and between 1 at night and 5 in the morning it is worth almost nothing. You can buy it for three cents a K. W. hour, and if the great producers of electricity simply look at the lighting curve and remember that that big load or peak is going to go on top of that railway peak at one time, they would see at a glance that they might as well generate that current in the small hours of the morning, and sell it at 15 cents per K. W. in the afternoon, rather than hunt for some consumer who will pay three cents for it in the early morning hours. So I think there is at least a prospect that my position may be right, but I hoped it would draw out discussion, and as I told Dr. Kennelly at the beginning, I hope you will not hesitate to punch holes all through the paper, but you have treated it very kindly so far.

MR. JESSE M. SMITH:—I had occasion a few years ago to make a test[1] of a small suburban electric road; 150 horse power engine, 150 horse-power generator, and I took readings every five seconds for 10 hours on the ammeter and voltmeter, and indicator cards every five minutes for the same length of time. The average load on that road throughout the day was less than one-third of the capacity of the generator. The average load on the engine was less than one-half of the rated capacity of the engine. There would be an excellent opportunity for a storage battery to equalize the load. The maximum load in that case never went above the rated capacity of either the engine or the generator. The average load on the engine was 70 indicated horse power. The average load on the generator was 45 electrical horse-power. I might say there were only three cars on the line, and the maximum load would come on and go off in less than five seconds. The load would vary from 81 I. H. P. to a maximum of 141 I. H. P. in less than five seconds, and that happened probably a hundred times in the day.

MR. F. S. HOLMES:—We should not lose sight of the fact that the extreme variations, which have been called "fluctuations," are characteristic of small stations rather than of large, and that the larger the station the steadier the load. I have seen the same conditions prevail in a power station of about the size spoken of

1. See Proceeding *Am. Soc. Mech. Engs.* Vol. XV. Page 780.

by the last speaker, where perhaps five or six cars were taking current. Now if you make that 25 cars, the load, by the law of general average, will be less subject to variations.

Some time ago I was called in to advise a certain concern on electrical matters. The people knew a great deal less about mechanics than they did about some other matters. They were extremely shy of electricity, because they had had very disastrous experience with some electric apparatus That apparatus happened to be a storage battery which was less than two years old, and was perfectly dry. I was not surprised, because upon visiting the engine room I found evidences of a primitive style of electrical operation—switchboards that were very much out of date, and electrical apparatus that was very poorly hooked up. If one is going to get the conditions that have been suggested by the first speaker, where there shall be nothing allowed for depreciation, then a very considerable amount must be allowed for the brains of the mechanic who takes care of the plant.

Before sitting down, however, I ought to say that I am very much in sympathy with the general statements of this paper. I agree with the speaker entirely in his statements in regard to the economies of an engine under a full and constant load. I suspect that that engine, that "plumed itself," according to the second speaker, on its ability to maintain an economical rate between wide ranges, was a compound engine. Cylinder condensation and clearances in engines of that character would not make them the most economical engines to run under conditions of sudden and wide variations.

MR. MAILLOUX:—I would like to disabuse the gentleman of the impression that because the plant is increased the fluctuations necessarily disappear. If he will look over the load curves which have been published in large numbers during the last year, and also the curves published in a paper on "Electric Railway Motor Tests" read before the INSTITUTE in 1892, he will find that fluctuations occur in a space of a few seconds, sometimes a few minutes, which may represent as much as 20 or 30 per cent. of the generator capacity of the plant, even with a plant of over two thousand horse-power capacity. Hence while the fluctuations may not be instantaneous in the sense that they are with a little three-car plant, yet since they take place within a period of time so short they must be considered as fluctuations, because they are just as important in their effect on the plant economy, and produce just as much discomfort to the station attendants, if not danger to the generating machinery as the fluctuations, as in the case of a three-car plant. It may be said that while the little kinks, or the ripples in the curve of fluctuation are smoothed out to some extent in the manner stated, yet it is by no means true that they disappear altogether, or at least to such an extent that provision should not be made to equalize them. The particular case that I referred to was the electric station at Minneapolis, to which I made a

somewhat detailed reference in my own paper. It will usually be found that the economies obtained even with stations of that kind are quite disastrous when compared with the theoretically attainable economies.

MR. H. B. COHO:—I had an experience with the storage battery some years ago, about the time of which Mr. Mailloux speaks, and find it difficult to grow enthusiastic on the subject of repairs. I remember, in 1892, operating a storage battery car. We had one car in service, and after two months intermittent service without renewing cells I wrote to the president of the company stating that at last we had attained perfection and would make our fortunes. Two days after I had sent this enthusiastic letter, my motorman came to me and stated that there was something wrong. I casually remarked that trouble was due to the motor and dismissed the subject. The next day we could do nothing whatever with the battery, it having gone to pieces entirely.

From the above experience I am strongly in favor of giving the matter of depreciation very careful consideration. I do not feel that the 10 per cent. depreciation which Mr. Lloyd figures on for machinery is as fair to the machines as it is to the battery. I agree that it is only fair to tell the prospective purchaser of a battery that his renewals may equal 10 per cent. per year, while I do not feel that it is fair to say he must charge off ten per cent. per year against his electrical machinery, as to all practical purposes his steam plant may be just as operative ten years after starting as it is in the beginning, and nothing like 100 per cent. of the cost has to be expended in renewals. On the other hand, we must admit that batteries must be renewed and new batteries put in from time to time.

This whole matter really boils itself down to one of dollars and cents, and while I think we all agree as to the advantage of the battery in a great number of instances, yet I would certainly recommend the station managers and others contemplating the use of batteries, to consult with skilled engineers before going ahead too rapidly.

I agree with Mr. Hill that there are advantages to be gained in making the working parts of his engine large in proportion to his cylinders, and that he gets a more easily operated plant as regards attention by doing so. For a building the size he mentions, a storage battery is undoubtedly a good thing, although I take issue with him on the subject of renewals. He wants to look out not to find himself in the position of the Deacon with his "one horse shay."

In conclusion I would say again that I believe the installing of a storage battery in connection with generating plants is altogether one of dollars and cents, and that due consideration must be given to the subject of repairs, and that it is hardly fair to say that a steam generating plant deteriorates 10 per cent. per annum in regular use. Improvements of course have their

effect in cutting down the value of machinery, but second-hand machinery always has a value, while the value of a second-hand storage battery is still a problem.

MR. MAILLOUX:—If no one else wishes to speak, there is another point that I would like to dwell upon. It is related to this question of depreciation. I have made several contracts for depreciation. I consider that the concern furnishing the battery, if the circumstance allow it, is the proper party to look after the maintenance of the battery, and that, other things being equal, it can do it more satisfactorily and more cheaply than the purchaser. I have generally, in preliminary estimates, taken 10 per cent. depreciation on the cost of the battery, but I must state that the contracts I have made have never exceeded 8 per cent., and I believe that in actual practice, the battery when not subjected to abuse, can be maintained for probably 7 per cent. In lighting stations the maintenance is even less, which, by the way, is due primarily to the fact that the battery has a relatively larger quantity factor; but where the battery is subject to fluctuations, using the term in the sense which I define, it generally depreciates somewhat faster and a greater allowance should be made for depreciation. I have seen cases where ten per cent. would not be too much allowance for depreciation.

In a thorough study which I made of the matter while in Europe, some three years ago, I found that the percentage of depreciation in continental installations of a size such as are installed, for instance, in Germany, at Hanover, Dusseldorf and Berlin, in the central stations, and in other places, the percentage of depreciation does not exceed five per cent. per annum. In most cases the central station company itself maintains the battery, and the total cost, including all expenses, does not exceed four per cent. A point of importance which I wish to allude to is that the size of the battery which one can afford and which one ought to put into a central station depends upon the percentage of depreciation. The lower the cost of depreciation, the more battery one can afford to put into a central station, the more one should put in, in order to obtain the maximum economy. This point is based upon mathematical relations which become perfectly apparent even on elementary study.

MR. JOSEPH BIJUR:—There are two questions that I should like to ask Mr. Lloyd. The first is, does he consider that the battery is as much an essential part of any station, railway or lighting station, as the engine, boiler and dynamo? In other words, is an engineer designing a plant to immediately assume that the battery will be used in any case, irrespective of the load? Does he think that the battery has developed to a point where its use will be always advantageous, or, are there cases where a battery may not be advisable?

The other point on which I would request some information is the reason for the very large difference of opinion that still

exists, I think, as to the use of batteries in large stations. I have seen both here and abroad a great difference of opinion in that respect. I recall particularly, that in Berlin, in 1893, they were operating about four different stations with large units, and the management did not believe in a battery at all. They thought that the best method of operation was to shut down or start up generators, as the case might be, corresponding to the requirements of the load. As three or four of their stations were tied together, when the load for any single station became too light, they simply shut that station down, transferring its load to another station. This was a lighting plant, so that at times of light load one station was carrying the whole city. I have seen the same thing done in railroad practice where two stations were tied together. On the other hand, in a city not very far away, they thought it quite essential to use a battery and the battery was used, I think, in the proportion that Mr. Lloyd suggests, that is some 70 per cent. battery to 30 per cent. machinery, and there was no apparent reason why these two companies should hold such different opinions. They could buy the same make of battery, and yet this distinction existed, and I think we find the same difference of opinion in this country.

MR. LLOYD:—I want to explain a little more clearly what I meant by depreciation in this paper. I see it is not very plain. Both in machinery and other apparatus, it is hardly likely that any will be in use, as I said, much more than twenty years, a great deal not more than ten years. If it is not worn out it will be out of date and the man will throw it away and get something else. In the case of steam engines, it is very likely that the use of superheated steam, especially with constant loads, will revolutionize steam practice. I do not say that it will, but it is one of the possibilities; and we always have to look forward to the direct production of electrical energy from coal without any steam engine, and I do not think that I should want to own a plant in which some allowance was not being made for the eventual throwing away of the whole apparatus in the course of ten or fifteen years, and while the actual repairs to the machinery might not be more than two per cent. per annum to keep it in good working order, it is very likely that the apparatus itself would be thrown out or the roads would be consolidated, or something else happen that would render that machinery useless in the course of a dozen years. In regard to the battery, the depreciation might be nothing for five years, and then a new set of positive plates, or a new set of negative plates goes into it, so that while the actual repairs and care of the battery, amount to very little, there must still be an allowance for renewal of plates. A battery has the slight advantage that in adding plates from year to year, or at intervals of three or four years, you add the best ones that are made at that time. You are not simply repairing an old machine, but you are putting in new machines that are up to date,

and I think likely that the man has a better battery than he had before. I know a number of the plants that have been spoken of to-night where renewals have been made, better stuff has been put in the battery, and the batteries are better now, and after ten years a battery will be a little more up-to-date than it was when it started, though even then it may be thrown away on account, as I said, of possible consolidations or for a thousand other reasons. I take 10 per cent. as being conservative also, because a good many railway engineers have told me that they are positive that their flywheels and their bed-plates, and other parts of their engines are crystalizing in such a way as to make them dangerous in the course of time. Even if they keep up bearings and other things, certain other parts of the machinery are liable to changes in the constitution of the metal, and they will be afraid to run them when twenty years old. In the particular station that I have referred to here, the real reason for the excess of maximum capacity is very plain, and probably applies to a great many others; that is, that the engines cannot be run at a maximum load or anything like it, even allowing for setting the circuit breakers a good deal beyond the maximum load. If these engines are running at full speed and with full consumption of steam, and the circuit breaker goes out, the engine runs away a revolution or two, and the result has been in this particular station since one of the pedestals broke down, and came very near wrecking the station, that you cannot get the engineers in attendance to run the engines in that way, and I have no doubt that this is true of other stations. There are other reasons, of course—economy and all that sort of thing. But it is simply impossible to run a station when the engineers are afraid of flywheels or anything else giving out, so they always have a great deal of reserve capacity.

In regard to the two points of the last speaker, I said in my paper that it was not safe to assume that the battery was always necessary. I think every case ought to be treated as a special problem. I know that there must be cases where a battery ought not to be assumed essential. In some localities water power is so cheap that it is not worth while storing energy, and there might be other conditions. We have attacked a good many problems in Pittsburg and took particular interest in them because coal was delivered at about 45 cents a ton, (slack coal), in the power-house of the Consolidated Traction Company there, and yet they found it best to add storage batteries to their installation, largely on account of the depreciation problem. They have put in magnificent machinery there, and they would not try to run it without a more steady load than the ordinary railway service would provide.

As to the difference in the views of engineers regarding the quantity of battery, and as to running big engines, I think time and experience will tend to establish a more uniform practice.

People have not yet discussed the subject sufficiently and there has not been enough data published, or enough effort made to obtain data. I am very sorry that my own paper is so incomplete in that respect. I hope some day that we shall be able to present a really thorough research in this class of work.

I referred in this paper to a way of using batteries that I thought perhaps some one might speak of; that is a possibility of simply using each generator with a constant load as it was added on, so that the day's load in a lighting station would be a series of steps, but each generator that was put in service would, by means of a battery of medium capacity, have a steady load. But I think that it would be very difficult for an engineer of a station to follow these steps and put generators on just when they are needed; and for that reason I have not allowed the the same economy in running engines that way as in a station where the engineer is perfectly sure of what his load factors will be every day.

Mr. President, have I answered all the questions?

THE PRESIDENT:—I think so, Mr. Lloyd.

MR. BIRDSALL:—In these days when we are struggling to get the last cent out of everything and the last watt out of every pound of coal, it is quite discouraging to run across a peculiar plant, and I did it about a month ago. I was called upon to make a test of a plant to see if it could not be improved, as they thought that there was room for improvement. The plant was in a town of, I think, about 110,000 people. It consisted of two sheds; one contained the boilers and the other the engines and the dynamos. It was alongside of the railroad, so that they dumped the coal right from the cars into the boiler room. They had, I think, three or four horizontal tubular boilers and one Heine. Nothing of the boilers was covered, except by the brickwork at the side. The steam pipe was also bare. They had one cross-compound high-speed engine, non-condensing; two smaller high-speed engines, two Westinghouse standard engines, all belted to dynamos of various vintages. Everything that was a back number and everything that was queer they had there. They had a wooden switchboard with the finest collection on it that I ever saw. They had one of everything. They evidently had called for samples and put them up. The man who owned two-thirds of the station after taking me around it said "What do you think of it?" Well, I did not dare to tell him; I would have lost my job, as they say, right there and then if I had. I made notes of the machinery and then went back to the office. He said "I don't think that it is earning as much money as it should." Well, that was my opinion too; that is what I thought then. We went back to the office and went over the earnings. In the station everything was dirty. The boiler room was not fit to pile coal in. It was simply the worst I ever saw; and we went back and went over

the books. The man that I was with was the president and owned two-thirds of it. Another man was secretary and treasurer; he owned the other third, except one or two shares, which somebody's wife owned, in order to make up the board of directors. That was the only station in the town. Upon going over the books we found that they had a capital of $25,000. They had machinery that must have cost them $40,000 at the time when they bought it, when the question was "How much has the man got?" not "What is the machinery worth?" They had capital stock of $25,000 and no bonds. They also had a surplus of $25,000 in the treasury. I saw that with great gratification. Then I saw that they had paid no dividends whatever since the plant started; but they had paid the president an average salary of $20,000 a year, and the secretary and treasurer an average salary of $10,000 a year. He said "Where do you see any chance for improvement?" I confess I did not see as much as I did when in the station.

As to the matter of the peak of the load I would say that I am running a road now in which we have about 40 cars and very few grades, and the load varies almost as much as it did when we only ran 10 cars on it. On holidays and Sundays when the traffic is bunched at a park on one end of the line, by that marvelous second sight that motormen have, to start every car at once, they open the circuit breakers very frequently. After the cars get started it appears to break the endless mental chain between the motormen.

[Adjourned.]

Discussion in Chicago.

A meeting of Western members was held at the Technical Club, Chicago, February 15th, 1899. The Local Honorary Secretary, Mr. R. H. Pierce presided, and the paper was read by Mr. B. J. Arnold.

The Chairman [Mr. R. H. Pierce]:—This paper, with all other papers on the same subject, necessarily makes a comparison between the first cost and the depreciation of electric storage batteries and steam plants. It also brings up the question of what is the cost of a steam plant per horse-power, and what ought to be the cost of producing a horse-power. This ought to open a wide field of discussion. I notice that Mr. Dow is present. From what he has told me about his own experience, he ought to be able to discuss this phase of the question. We have some figures of very cheap power here, which I think some one who is in that business ought to take up.

Mr. Alex Dow;—I am very much interested as a mechanical engineer, because the figures quoted of $2\frac{1}{10}$ lbs of coal and 3 lbs. of coal per kilowatt hour, and so on, are figures of very high economy. They are only obtained in the largest power plants, and under favorable conditions. In lighting stations they are very exceptional.

The remark interpolated by Mr. Arnold with regard to the number of pounds of coal per kilowatt hour is strictly true, I regret to say. I have stations on my hands now that don't come down to nine pounds per kilowatt hour, and the best record in my own practice is five pounds for the 24 hours, and approximately four pounds on favorable occasions, with Ohio coal and series dynamos.

I have had occasion recently to consider the use of the battery which is classified is "small," to secure regulation at a distant point. The investigation took me into several lines of inquiry, and incidentally caused me to go over all the data that I had, and to make some experiments as to what could be done to control momentary fluctuations, and to take care of instantaneous variations of loads such as are shown in the curves here, while retaining a given steam economy; not to take care of them in the manner indicated in Fig. 1 by putting on an engine a great deal too large for the work, but to take care of them with an engine which would be economical under the actual conditions. I have found that the practice in a great majority of plants is to have an engine entirely too large for economy. I confirm most emphatically Mr. Lloyd's statement that in many stations the engine is too large even for the maximum demand; and that brought distinctly to my mind the idea that there is still much to be done in the way of adapting the steam engine to the actual conditions of electric lighting and power. Much can be done in the way of a proper proportioning of cylinders—usually in

reducing piston area, while keeping the reciprocating parts of the engine strong enough for instantaneous maxima, and using valve gear that will allow a late cut-off. I find that it is possible with such an engine to take care of fluctuations away beyond the nominal capacity of the set, by merely having plenty of fly-wheel. I find that instantaneous loads of 10 or 15 per cent. above the generator capacity can be disregarded altogether; that the average of the load can be provided for by the proper selection of engine cylinders and cut-off in conjunction with a much heavier frame than is usual. The strong frame and reciprocating parts ensure that there will be no strains of an injurious character produced by those instantaneous loads in the engine itself. The generator of now-a-days does not break down under such conditions. Formerly, we used to strip armature windings when they got a sudden short-circuit or a sudden overload, but as the generators are now built, they don't do that. I should say the function of the "small" battery is not to take care of instantaneous variations which can be perfectly well taken care of by a steam engine; but is to take care of local variations which are complicated by copper losses in the line. I believe that the place for the "small" battery so-called, is on the outlying feeders where it can equalize drop in line and hold up the local pressure. I believe that the distribution of several such "small" batteries over a street railway system would be excellent engineering, and give good results when a similar amount of battery installed at the station would not be profitable or desirable. It would permit the doing of one thing the value of which is only occasionally appreciated; it would permit the use of copper adapted to the average load on the feeder rather than to the maximum.

The function of the "small" battery seems to me to be entirely to take care of local, single feeders. If anything should go in the station at all, it should be at least the "medium" battery, though the author advocates the so-called "large" battery. I think Mr. Lloyd is deserving the thanks of electrical engineers generally for those three expressions. They define very distinctly the work which is required of storage batteries under different conditions, and I hope they will be adopted by people generally who are carrying on that class of engineering.

THE CHAIRMAN:—I would like to ask Mr. Dow what, in the light of his recent experience in central station work, he thinks of the proposition of producing 557 watt hours from a pound of coal.

MR. DOW:—I think it is absurd. It is only possible to approximate it with a storage battery of the largest size.

MR. MAURICE COSTER:—I would like to ask a question of the gentleman who represents the storage battery interests. I note that the author in his paper places depreciation and repairs at 10 per cent. I would like to know approximately just what per-

centage of this is to be charged to depreciation, and what percentage to repairs.

THE CHAIRMAN:—Mr. Appleton, you may answer that in your own way.

MR. JOSEPH APPLETON:—About six per cent., Mr. Coster, is very fair for depreciation.

MR. COSTER:—According to that it would be four per cent. for repairs.

MR. APPLETON:—Of course in a storage battery the depreciation is different from the depreciation of machinery. The way in which you provide for the depreciation of a storage battery is in time to renew the entire wearing parts of the battery. It is not the same in the depreciation of machinery. In taking care of the depreciation of a storage battery you renew entirely in time the parts which wear out, and therefore in a certain number of years you will have practically the battery in the same condition as when you began. Therefore the term depreciation of storage batteries bears a rather different meaning from the depreciation of machinery.

MR. COSTER:—In this connection I would like to express my opinion regarding depreciation of storage batteries, electrical machinery and engines. It is not safe for any engineer to estimate an amount less than ten per cent., per annum for depreciation. I was not surprised to hear that some engineers only allowed two per cent. I heard that a very prominent engineer recently made a similar estimate in the case of a large installation which cost over half a million dollars. I surprised one of the principal financial men in this enterprise by assuring him that this estimate was entirely too low, and that 10 per cent. a year should be allowed.

The generators and engines may be in a very good condition at the end of ten years, but in the course of that time there would have been so much advance made in the design, economy efficiency and style of mechanical and electrical apparatus that they would probably be able to afford to throw away the original installation. If this holds good regarding engines and dynamos it probably would be more true of storage batteries.

I do not wish anyone to think that I am not in favor of storage batteries. Three years ago when Mr. Arnold had occasion to install the first large storage battery plant in this city in the building of the Board of Trade, I did not think that it would be a success. I was, however, one of the first to compliment Mr. Arnold on the great success of this installation. We should, however, not deceive ourselves and our clients by allowing only two per cent. for depreciation. Let us come right down to facts, and estimate ten per cent. for depreciation of storage batteries, and other apparatus, and an additional four to six per cent. for wear and tear. I would like to hear the opinion of some of the other members on this subject.

MR. APPLETON:—I want to say a few words in reply to those remarks, for I do not think I have made myself perfectly understood perhaps. In the depreciation of an engine or piece of machinery at the end of ten years, a certain amount of money, possibly a great deal, may have been spent for repairs, but you still have the same main parts of the engine and machine as when you started. Now, if you put in a storage battery, at the end of ten years even with six per cent. depreciation you probably won't have the same plates that you started with; you have an entirely new set of plates. Now, if there have been any improvements made in that time you are enabled to get the benefits of those improvements for the same amount of depreciation. The case is entirely different from the repairs and maintenance of any machinery such as engines, boilers or dynamos.

MR. COSTER:—Do you not expect, in the course of ten years to have something in storage batteries a great deal more efficient and better than you have to-day?

MR. APPLETON:—Well, we will have, and still, as I say, the only parts remaining will be the tanks and electrolyte.

MR. COSTER:—How do you know that you will need any tanks after ten years?

THE CHAIRMAN:—Mr. Knox, the Electrical Engineer of the Chicago City Railway Company, is with us, and I am sure that we shall be pleased to hear from him, as among the people that are directly interested in the question of the application of the battery to railway work.

MR. KNOX:—I came here merely to listen and learn. I will say, however, that in my case, as with most people, first impressions are often the most lasting. I mean by this that about the time I started in railway work I was sent to Dubuque, Iowa, to replace a storage battery road, which had proven unsatisfactory, with the overhead system, and that rather influenced me in thinking that the storage battery was not exactly what was wanted in street railway work. I will say, however, that at this time I am inclined to be a little more liberal, as there have certainly been great developments in the application of the storage battery, more particularly, in central station work, and of late in the railway field. I have been watching with great interest the developments along this line.

I can not agree with Mr. Dow in believing that it will pay to install a small battery at the ends of trolley lines to take care of the fluctuations. It will take some research and close estimating to see where the economy will come in. Although the efficiency of our motors is lowered as our voltage out on the line drops, it really does no particularly harm to the motors to run for a brief period at the lower voltage, even with a drop on the line as high as 15 per cent. So as I was saying, I believe it will take some close estimating to see where by the installation of the small battery to take up the fluctuations it will be found a paying investment.

MR. ARNOLD:—I would like to ask Mr. Knox whether in the distribution system of the railway company which he represents, the drop of ten or 15 per cent. is the total drop from the power station.

MR. KNOX:—No. The drop on line.

MR. ARNOLD:—If not, what is the probable maximum?

MR. KNOX:—I have places on the line where I have to take care of as high as a 20 per cent drop. This of course is bad practice. But there is a condition that governs this state of affairs, inasmuch as we are short on the required conduit room, and we are also limited on the street where we carry our overhead wires as to their number, and on account of the liability of change of conditions in the system of distribution we do not know just at this time whether it is policy to figure on running any more feeders to the point where we have the 20 per cent. drop to take care of it. I refer to the Clark street line. But as a whole, outside of the Clark street line, we haven't on our system after a thorough test, over a seven or eight per cent. average drop. This represents the maximum average, the general average ranges as low as $6\frac{5}{6}$ per cent. Of course we run a great deal of copper, and we have what we believe to be the most approved rail return in the shape of cast weld joints and immense quantities of copper cables, resulting in the saving of a great deal of the drop usually found in railway work.

MR. DOW:—I would like to ask Mr. Knox whether those drops are averages, or whether they are the maximum.

MR. KNOX:—I refer to the eight per cent. as the maximum average.

MR. DOW:—And that covers the instantaneous drop, for instance, resulting from starting several cars simultaneously.

MR. KNOX:—Oh, no.

MR. DOW:—What is it under those conditions?

MR. KNOX:—Well, we get 12 to 15 per cent.; no more than that.

MR. ARNOLD:—I think, Mr. Chairman, that the railway which Mr. Knox represents is particularly well located to keep its average loss so low. Take the case of a long-distance road where the power station is quite a distance from each end of the line. I think it would take a great deal of copper to keep the average drop up to anywhere near the figures given by Mr. Knox. But with power stations located somewhere near the center of a radiating system you would have a condition which would make it possible to hold the voltage up as Mr. Knox states. I think in the long-distance scheme that the regulating battery is required at the end of long feeders.

THE CHAIRMAN:—As Mr. Appleton will probably be more familiar with the subject matter of this paper than the rest of us I would like to ask for our information regarding these watt-hours per pounds of coal. On page 64 of the paper I under-

stand that the theoretical cost of operation, with a storage battery, is figured on the basis of 557 watt-hours per pound of coal, and that the result obtained from figuring on this basis is compared on the next page with the actual results obtained in practice. No statement is made as to how many watts were obtained from a pound of coal *in practice*. Of course I suppose they get just about half that result; that is to say, they would get about half as good a result as in the theoretical case.

MR. DOW:—We figure a horse-power indicated for 1.12 pounds of coal, which is a little too good.

THE CHAIRMAN:—I figured it over as the paper was being read and made it about 1.20 lbs. I think it would be fair to figure the combined efficiency of a generator set at not over 87 per cent.

MR. DOW:—I figure it 85 per cent

MR. APPLETON:—I may say, Mr. Chairman, I am not very familiar with the figures given in the paper.

MR. DOW:—I think there is a decimal missing there, Mr. Chairman.

THE CHAIRMAN:—As I understand the paper, the cost of producing the power on that basis is compared with results which were actually obtained in practice. The author of the paper, on page 62 criticizes Mr. Conant and says that none of his stations showed better than 3 pounds per killowatt hour. Now, take 15 tons of coal, running on a basis of 3 pounds of coal per kilowatt hour, and those figures would show a conclusion quite different from what the author seems to have drawn.

Now I would like to ask another question: The author of this paper has stated what he figures to be the cost of the generating plant complete, including stations, at $100 per kilowatt. I think we would all be interested in knowing at what price he has figured the battery per kilowatt in making the comparison.

MR. ARNOLD:—He says distinctly without batteries.

THE CHAIRMAN:—Yes, but in other places he has compared, without giving figures, the cost of the plant with and without batteries.

MR. ARNOLD:—The price entirely depends upon the rate of discharge required of the battery. It may vary from $40 to $175 depending upon the rate.

THE CHAIRMAN:—Per kilowatt hour?

MR. ARNOLD:—Yes.

THE CHAIRMAN:—To what variation do those figures correspond?

MR. ARNOLD:—The price of a battery depends entirely upon the time in which you take its capacity out of it. In other words, if you discharge a battery in one hour you only get about one-half as much out of it as you would if you discharged it over a period of eight hours, so that its price would be double what it

would be at the eight hour rate; so that when you figure batteries at so much per kilowatt hour you must know at what rate you expect to discharge. If they can be discharged over the entire period of eight hours they can be brought down as low as $40 per kilowatt hour. Prices are advancing now, and as I am not in the battery business at present, I am not absolutely sure of present figures but we have figured them as low as $35 per kilowatt hour. If you go up to the one hour rate I think it will be as high as $100, and perhaps in some cases on a half hour rate the figures which I stated a moment ago, $175. There are curves in existence which I had a hand in the preparation of, by which you can tell the cost of a battery if you determine the rate at which you want it discharged. It varies from $35 up.

MR. APPLETON:—With regard to the question which Mr. Dow raised about the regulating effect of a "small" battery, I have a case in mind now where a "small" battery is put at the end of a long feeder nine miles away from the power-house. A sub station has been built at that distance from the power-house on a line extending about three or four miles beyond, and about three miles back towards the power-house. The maximum amount of current delivered from that power-house reaches as high as 1,000 amperes, but the average during the day is about 400 amperes. This 400 amperes is sent up over a feeder to the battery and is distributed as the load requires at any rate up to 1,000 amperes, the average amount being sent up of course instead of the maximum. The question of the regulating effect of batteries on railway loads is a very interesting one, especially as regards the efficiency of the battery and the amount of work actually done by the battery under such conditions.

Under those conditions the efficiency of the battery is high, because the charge and discharge are intermittent, and you are working the battery under the most efficient conditions. The amount of charge put into the battery is recorded by a wattmeter, and the amount taken out of the battery is recorded by a separate wattmeter, and the average monthly efficiencies are from 90 to 95 per cent., according to the care with which the charging is watched. This battery is given a little charge every night during the hours of light load, and if the men are careful to stop the charge or reduce the charge when the battery is full, the efficiency will reach as high as 95 per cent. in watt efficiency. That, of course, is very different from a battery which is entirely discharged at one discharge and then charged up again. In that case, the efficiency of course is not over 75 per cent.

The Metropolitan Street Railway Company in New York has really installed two large batteries that are not only for regulating purposes, but also for the purpose of taking a portion of the peak; they have one battery installed at the foot of West 23rd street, and there the peak in the afternoon lasts from about 4

until about half past 6, and the work done by the battery during that time is very interesting. Taking one day the maximum rate reached during that two hours and a half is 2,400 to 2,600 amperes. That is the maximum rate at which the battery discharges during that time. Yet the total amount of work done by the batteries during that two hours and a half does not exceed about 1,800 ampere hours, or an average for the two hours and a half of between 700 and 800 amperes discharged.

I have in mind another small station operating five cars supplied entirely by a rotary transformer. When the five cars are running, the fluctuations of course are very great. The maximum demand on the line is about 300 amperes, but that does not occur very often. At that time the maximum load on the rotary is about 100 or 125, or less than one-half, and the average load on the generator is about 80 amperes.

This shows very clearly how the battery used as a regulator in that way, will reduce the required capacity of generation on a rotary transformer. It think it is in this field particularly where the large use of storage batteries will be, as the use of rotaries has come into vogue so extensively.

The use of storage batteries at the power-house is of course different. But by the use of the battery at the feeder end you not only get an equalization of the load on the power-house, but you make a saving in the investment in copper. Whereas, with the battery at the power-house you use it for the better evening up of the load on the generator.

The whole question of the use of batteries for this purpose is best studied in the actual operation of a plant after the battery is put in. In laying out for the use of a battery in work of this sort you can see many advantages, but there are others which are peculiar and particular to each condition, which are not fully realized until you get the advantage of operation. It has been my experience that those in actual charge of the operation always find many more advantages and very different ones than those they were expecting when the plant was put in, and it is due to that as much as anything, I believe, that the use of the storage batteries is growing so in connection with this work.

MR. ARNOLD:—I think, Mr. Chairman, that one of the points brought out by Mr. Appleton is very important. I think that Mr. Appleton himself has only recently found it out—within the last few months I mean—and he is the only man who is in a position to find it out, and we are very fortunate in having him make it clear to us. That is the increased efficiency of a regulated battery over and above what we have always supposed it to be. We have always thought that if we got an efficiency of 80 per cent. out of a battery we are doing pretty well. Now Mr. Appleton informs us that the efficiency of the battery under those circumstances is as high as 95 per cent., and he backs the statement with tests which he has made, and the monthly records

of the charging and discharging of the battery. That certainly puts the battery on a much higher plane for one of the main purposes that it has always been advocated for; that shows that it is a remarkably efficient piece of apparatus, and that it is now in the same class as the static transformer or the rotary converter—getting in very good company.

MR. DOW:—Do I understand that the battery was discharged at quite a high rate and it was charged at short intervals?

MR. APPLETON:—The average current coming over that field was only 400 amperes, and therefore the rate of charging could not exceed 400. But the rate of discharge would be 600 at the the time of maximum load, and the thousand amperes or 400 amperes coming up over the feeder would be distributed as needed from the battery, making the total output 1000 amperes, that is, at moments of fluctuation caused by the cars getting bunched, coming up a hill, or something of that sort.

THE CHAIRMAN:—What would be the capacity of that battery based on the ordinary eight-hour discharge.

MR. APPLETON:—The battery has an hour rate of 600 amperes or 1200 amperes at an eight-hour rate.

THE CHAIRMAN:—That is all right.

MR. APPLETON:—Then we really would be charging and discharging simply as the load varies.

THE CHAIRMAN:—But at quite a high rate as compared with the figures that are ordinarily given for charging and discharging.

MR. APPLETON:—No, sir, the average load on that section never falls below about 200 amperes, therefore the battery hardly ever charges above 200 amperes, and that you see for a short time. The load in that section would never fall down to nothing. If it did fall down to nothing the rate of charge would be 400 amperes during that time, as 400 amperes is the ordinary current being sent up to that section over that feeder.

THE CHAIRMAN:—But a charge or discharge of 200 amperes on the battery.

MR. APPLETON:—I say a charge of 200 and a maximum discharge of 600.

THE CHAIRMAN:—Well, that rate of charge and discharge on a battery of the capacity of only 1200 ampere hours at the eight-hour rate, would really be a high rate, would it not?

MR. APPLETON:—It is only the one hour rate battery now, sir, which I think is almost universal for regulating work of that sort.

THE CHAIRMAN:—What I am trying to get at is, that this high efficiency which you get is due to the intermittent work on the battery. If it was charged and discharged at anything like that rate constantly you would not get that efficiency.

MR. APPLETON:—Certainly not, because the charge and discharge are not continued long enough to allow the voltage of the

battery to drop down in discharging or raise in charging to any appreciable extent. It does not give time for the gas to form on the plate. On the other hand, the discharge is not continued long enough to allow a great drop.

THE CHAIRMAN :—So that it is operated with the same advantage that you would get with an open circuit primary battery.

MR APPLETON :—Of course. The internal resistance of a primary battery would be so great that if any work was done at all it would drop down, but the internal resistance of the storage battery is so low that a discharge for a short time hardly decreases it at all. Your discharge is almost the same as an open circuit under those conditions. As a matter of fact batteries in regulating duty of this sort, work at an average of 2.08 volts. That is not the same value they would have if worked at a steady discharge extending over eight or ten hours.

THE CHAIRMAN :—The real work being on the straight part of the curve all the time. They don't get the loss that you get on the rise and fall, which is a great portion of the loss.

MR. APPLETON :—That is it exactly.

MR. DOW :—This variation was in watts.

MR. APPLETON :—Yes, as measured by a wattmeter.

MR. DOW :—As a mere matter of curiosity would you tell us what the ampere efficiency would be?

MR. APPLETON :—Well, in that connection I couldn't tell, sir, because we never measured it. I would say about two per cent. higher.

MR. DOW :—Then that demonstrates that the variation of voltage is very small.

MR. APPLETON :—It is very small indeed. You are operating almost at a constant voltage under those conditions.

Of course there is one point I would like to add in connection with that statement: That in order to obtain the best results, the number of cells must be very carefully adjusted to the average voltage at that point. If you have too few cells the battery will of necessity overcharge and destroy the efficiency.

[Adjourned subject to the call of the Secretary.]

[COMMUNICATED AFTER ADJOURNMENT BY MR. GEORGE HILL.]

Professor Elihu Thomson's discussion of Mr. S. Dana Greene's paper "Electricity on Board Ship" presented at the meeting of January 25th, 1899, calls for a comment on certain statements made which in the opinion of the writer are not borne out by the facts. The intimation is made that a simple single acting non-condensing steam engine can be made by a slight change from the standard design as economical as a triple-expansion condensing engine. The principle of the change is indicated by Professor Thomson in the statement that "I must imitate the cycle of the gas engine in steam, and then I would get high efficiency with other advantages." The cycle of a gas engine as ordinarily understood is as follows:

The admission of a certain amount of mixed gas and air during the forward stroke of the piston; the compression of this gas and air during the returning stroke of the piston; the explosion of this compressed mixture at the instant that the piston begins to move forward, the sweeping out of the products of this explosion on the return stroke of the piston, and the drawing in of a new charge of gas and air with the forward stroke beginning a new cycle. The cycle therefore occupies two complete revolutions, one of which may be called a working revolution and the other an idle one. Nothing in the engine described by Professor Thomson approaches this. In describing the action of the engine he says "now instead of reversing the motion of our steam as it enters back of the piston and throwing it back to the heated surfaces in exhausting, we are careful never to throw it back, but always let it go forward." Such a statement seems very curious from so eminent a source; the steam must act expansively; as a consequence the entire cylinder is filled with steam during the entire forward stroke at a constantly decreasing pressure and consequently a decreasing temperature. When the return stroke begins, the cylinder is filled with steam at atmospheric pressure and this steam is compressed giving the compression line shown in Fig. 2. The entire cylinder being filled with steam of a given temperature at the point of release, it really makes no difference at which end of the cylinder the steam is withdrawn. As a consequence, the engine is no different in principle from the Westinghouse engine. The steam consumption per horse-power hour seems very low, and would be remarkable if it were ordinary steam at 160 lbs. pressure without superheat but Professor Thomson states that superheated steam is used, without stating the number of degrees of superheat, which accounts for the low water consumption. If he had expressed the efficiency of the engine in heat units actually utilized or in pounds of coal of a stated composition per horse-power hour, the result would have appeared very different. The available heat in steam at 160 lbs. gauge pressure, expanded to atmospheric

pressure is 46 H. U. per pound, each degree of superheat adding to the available energy a considerable percentage, which percentage is greater than that due to an increase of one pound in pressure, but both require the expenditure of energy either by the consumption of coal or otherwise, and must be accounted for in stating the economy of the engine. Something too must be allowed for the fact that the engine tested was new, and probably a great deal of pains taken to eliminate all waste. In conclusion it would seem desirable to obtain much more data in regard to the engine and its operation before we flatter ourselves that any material advance had been made in steam engineering by either Professor Thomson or M. Serpollet.

New York, March 28th, 1899.

[A REPLY BY PROF. ELIHU THOMSON to Mr. Hill's comments on his discussion of Mr. S. D. Greene's paper on "Electricity on Board Ship."]

I am too busy to enter into a lengthy discussion with Mr. Hill on the points raised by him, but will venture, for the present, the following remarks:

My comments following Mr. Greene's paper were made offhand, and were not prepared in advance. They had necessarily to be brief, and nearly as possible to the point. I certainly did not intend to indicate that the best results of triple-expansion engine practice were likely to be excelled by the simple form of engine which I described. But that the effects of simple engines could be made to approach more nearly the highly economical results of more complex types is evident when it is borne in mind that our simple engine of only five and a fraction horsepower, in reality composed of four simple engines of little over one H.P. each, when tested, gave results in water consumption not greatly differing from those of tests of engines of hundreds of horse-power in compound condensing types. A factor in the cost of power is interest, wear and tear and depreciation, which are manifestly the less, the simpler and cheaper the engine, other things being equal. Mr. Hill finds fault with my comparison of the cycle of the small engine with that of a gas engine, seemingly ignoring those types of single cylinder gas engine which make one explosion every revolution. He must admit, however, that in the simple engine, an action is produced every revolution which in the type of gas engine he selects for comparison is only produced for every other revolution, and that in consequence the simple steam engine described has the advantage of less friction and negative work. Besides, I was speaking only in general terms when I referred to the gas engine

cycle, and merely as an assistance to the understanding of the actions in the simpler engine itself.

We have indeed to be thankful that:—"Nothing in the engine described by Prof. Thomson approaches" the *idle* revolution of the four stroke cycle of the gas engine. I am surprised at Mr. Hill's not understanding what was meant by the statement I made in the words; "throwing it back to the heated surfaces in exhausting," etc. He has totally missed the significance of the words "*in exhausting*." Does he find that the steam goes back to the hot end and out of that end *in exhausting?* It does go back (what amount is left of it) *in compressing*. This is so plainly evident as to need no discussion, and it is certainly not a bad feature. It is not a wasteful process, surely.

Does Mr. Hill really think, and can he truthfully maintain that "it makes no difference at which end of the cylinder the steam is withdrawn? If one end is hot, as heated by the incoming steam at high pressure, is it economical to discharge steam, *cooled* by expansion and delivery of energy to the moving piston, at the hot end, and so allow the steam in exhausting to run away with useful heat? What a beautifully wasteful process is that which involves the admission of steam between or over surfaces which have just been bathed in cool steam (and perhaps condensed water) leaving the cylinder. I freely admit that the fact of the use of superheated steam, has perhaps something to do with the low water consumption shown by repeated tests, and preparations are being made to test a much larger engine of the same type, with steam in all degrees of humidity, dryness and superheat.

As I was testing *an engine* and not *a boiler*, I rather preferred to exclude the boiler from the tests, particularly as no means were at hand to do differently. Just why this was the case I cannot stop to explain now. It is true that to obtain hot, dry steam, may mean the communication of more heat units per pound of steam than in the case of wet steam or saturated vapor, but the difference is comparatively slight. The change of state involved in boiling the water is, as Mr. Hill must know, the chief factor in the case, whether the steam be produced in one condition or another.

I cannot admit that: "A great deal of pains was taken to eliminate all waste." The engine was in good condition, of course, but not exceptionally so. Its simple construction permits of relatively easy maintenance. When I made the engine I expected to realize a result of about 30 pounds of dry steam per brake horse-power hour, which in itself would have been roughly about twice as economical a result as is shown in the best tests of such very small engines, of which I was able to obtain any data. I was skeptical of the result of the first tests, and freely expressed my doubts, but by going over the work and watching it personally, while insisting that everything be done to have the

errors count against the engine rather than in favor of it, I became convinced that my expectations had been greatly exceeded, and that a result of 20 pounds per horse-power hour, or slightly better than that, had been in fact, obtained, as I have indicated.

It remains to finish and test an engine of larger capacity and to do it under such varied conditions as will be likely to point out the relative values of those features which undoubtedly contribute to the still lower consumption which will probably be obtained.

The small engine tested was designed for automobile work, it being regarded as extremely desirable that but little water and fuel be carried, and but little steam escape during work. The clearance is great and the manner of exhaust and admission such that no trouble is ever experienced with condensed water in starting.

The engine is now in use upon a steam automobile, having a coil-pipe boiler heated by ordinary kerosene. It runs satisfactorily even under the very extreme condition, adopted in some experiments with it, of a steam supply-pipe at a bright red heat. But this is, of course, abnormal and only indicates the wide range in character of steam which is permissible. That it is not injured by excessive heat in the steam supplied, is due, doubtless, to the poppet valve admission and the extremely early cut-off which permits the entrance of only a momentary puff of hot steam when the piston is full in.

As a matter of interest in this connection I would conclude by calling attention to the fact that Ewing in his work on "The Steam Engine, and other Heat Engines," on pages 160 and 161 gives some results of tests by Willans on a small, simple, non-condensing single-cylinder engine, in which, with 172 pounds of steam, an indicated horse-power hour was obtainable with 18½ lbs. of steam. This represents, as Ewing points out, an efficiency of 75 per cent. of the theoretical efficiency of an engine working under the conditions. Ewing also refers in this connection to "*Min. Pro. Inst. C. E.*, vol. xiii., part 3, and vol. xcvi., part 2," in a foot note.

Lynn, Mass., April 5th, 1899.

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